Coastal Ocean Modeling and Observation Program:
Real-time Adaptive Sampling Networks

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LONG-TERM GOALS

The long-term goal of our coordinated ONR (COMOP/HyCODE) and NOPP research efforts is the development and validation of a relocatable coastal ocean forecasting system consisting of a coupled atmospheric-hydrodynamic-optical data-assimilative numerical model and a multi-platform real-time adaptive sampling network for use in physical/bio-optical applications worldwide.

OBJECTIVES

Specific current objectives include: (a) Implementation of a comprehensive coastal prediction system incorporating atmospheric, benthic and bio-optical submodels; (b) Construction of shipboard/autonomous subsurface sampling network beneath spatially extensive remotely sensed surface observations; (c) Development of data-assimilative and visualization interfaces for model-directed adaptive sampling; and (d) Evaluation of nowcast/forecast skill in multiple regions.

APPROACH

We are conducting a series of Coastal Predictive Skill Experiments (CPSE) each summer at the Long-term Ecosystem Observatory (LEO-15) offshore Tuckerton, NJ. Model and observation network improvements tested each winter with existing data are used in an operational setting the following summer. Our phenomenological focus is on the physics of the recurrent upwelling centers that form along the southern New Jersey coast and their impact on phytoplankton distributions, in-water optical properties and dissolved oxygen. Coordinated shipboard (physical and bio-optical) and multiple AUV

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adaptive sampling surveys of the upwelling centers are conducted based on real-time remote sensing and in situ observations and model forecasts.

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WORK COMPLETED

The Rutgers Regional Ocean Modeling System (ROMS) was configured for the New York Bight and run in real-time during the July, 1998 CSPE with surface forcing supplied by operational Navy atmospheric models (NOGAPS/NORAPS). In preparation for the July 1999 CPSE, modeling work focused on improving ROMS boundary conditions and internal turbulence parameterizations. The Regional Atmospheric Modeling System (RAMS) was configured at high-resolution (4 km) for the Middle Atlantic Bight. Access to lower resolution (27 km) Navy COAMPS atmospheric forecasts was established through NLMOC and MEL. The COARE implementation of the atmospheric boundary layer was added to couple the ROMS ocean model to either the RAMS or COAMPS atmospheric forecasts. Lateral boundary conditions were improved using the Raymond and Kuo 2-d radiation condition, eliminating the need for a sponge layer. The K Profile Parameterization (KPP) surface boundary layer turbulence closure scheme (Large et al., 19??) was modified for shallow water to include a bottom boundary layer that potentially overlaps much of the surface layer. The Styles and Glenn (1999) Bottom Boundary Layer Model (BBLM) was modified to run efficiently in numerical models and was coupled to ROMS to include the effects of wave-current interactions and ripple formation on the bottom boundary condition. The ROMS circulation model continues to be advanced. Additional ROMS improvements over the past year include: the addition of conservative parabolic splines for vertical differencing, more efficient time-stepping schemes for 3D momentum and tracers, the re-introduction of an option for Mellor-Yamada turbulent mixing (to allow direct comparison with the new KPP/BBLM formulation), and the preparation of a unified shared and distributed memory code for high-performance computing across a range of available platforms.

Numerous remote sensing, moored, shipboard and AUV datasets from the 1998 CPSE were processed over the winter with emphasis on sensor validation. An intense two-month duration effort to rescue the 1998 ADCP data from all the REMUS AUVs (WHOI and NUWC) concluded with its successful validation against moored ADCPs located near the start and end points of the cross-shelf transects. Detiding techniques were developed and tested for the numerous towed and REMUS ADCP transects.

CODAR radial surface current fields (raw, tidal and detided) were validated against moored, towed and REMUS ADCP data. New cloud detection algorithms were developed for the AVHRR derived SSTs to produce a series of declouded daytime and nighttime images for use by both the ocean and atmospheric models and for comparison with moored thermister string data. SeaWiFS imagery sensitivities to the negative water leaving radiances were investigated with SeaSpace and NRL. The Rutgers Ocean Data Access Network (RODAN) was developed to provide interactive web access to the numerous processed datasets.

Intense preparation for the 1999 CPSE experiment began in the spring. Towed vehicles (surface SWATH ADCP and the undulating MiniBat CTD) were upgraded based on the previous year's experience. The towing vessel (R/V Caleta) was equipped with a computer network and a RF bridge to our shore facility using freewave modems. The communication network enables (a) shore-based researchers to view the same real-time SWATH ADCP and MiniBat CTD computer displays seen on the boat, (b) the transfer of ADCP and CTD data files to shore for immediate processing and display on the web, and (c) scientists at sea access to the numerous real-time datasets displayed on the web. Numerous processing algorithms, web display scripts and Java Applets were developed to enable widespread distribution and interactive display of the real-time datasets for use in adaptive sampling mission planning. A CTD calibration facility was set up at Tuckerton to cross-calibrate the numerous moored, shipboard and AUV CTDs. Upgrades of the local meteorological sensors were initiated, including installation of a shore-based SODAR atmospheric profiler.

The 1999 CPSE was conducted during July 1999. Over 120 scientists, engineers, students, visitors, and middle school teachers participated. An extensive real-time observation network consisting of satellite SST and ocean color, CODAR surface currents, meteorological data, remotely operated subsurface ADCP/CTD profilers and thermister string arrays was operated. Atmosphere and ocean forecasts were generated in real time for seven forecast intervals during the July 1999 CSPE. RAMS was forced with National Center for Environmental Prediction (NCEP) global Eta and AVN models with ocean feedback provided by persisted satellite-derived SSTs. Ocean forecasts assimilated temperature and salinity data via Optimal Interpolation (OI) and CODAR surface currents via nudging. By the end of the experiment, 3-d MODAS fields generated by NRL were used for initialization. Surface waves were assumed spatially uniform and persisted. Atmospheric and oceanic forecast products were posted on the web as they where produced.

Data-based nowcasts and atmospheric/ocean forecasts where used to plan adaptive sampling surveys with a fleet of 7 research vessels and 5 AUVs. Guided by this information, the R/V Caleta (17 missions, 1111 km surveyed) and REMUS (8 missions, 377 km surveyed) provided additional subsurface ADCP and CTD coverage for feature identification, assimilation and mission planning. The Webb Coastal Electric Glider completed its first sea trials, including transmission to shore of several CTD casts that were immediately processed, transferred to NRL and assimilated in that evening's MODAS forecast. The complete suite of information was used to guide the R/V Walford on 23 bio-optical sampling missions, the NUWC REMUS on 11 turbulence sampling missions, the Northstar IV on 5 and the Arabella on 3 biological sampling missions.

We continue to evaluate various alternatives for assimilation of multiple data-streams into ROMS. During the past year, we have worked with colleagues at Scripps Institution of Oceanography (Miller, PI) to build an adjoint for the ROMS circulation model. Attempts to do so via the Gering automatic adjoint compiler proved unsuccessful due to an inability of the compiler to accept some of the coding practices currently being employed in ROMS. Alternative approaches to adjoint generation are being sought. Meanwhile, we plan to evaluate feasibility and performance of data assimilation via error subspace statistical estimation (as used in the HOPS system) beginning in November 1999.

The success of the real-time synchronous (but line-of-sight) ship-to-shore communications have led us to partner with PinOak Digital to develop asynchronous (but global) communication systems for our adaptive sampling fleet. Using Single Side Band radio and a digital modem, we are preparing to test asynchronous transfers (email message format) between our ships and shore.

RESULTS

The RAMS forecasts reveal the high spatial and temporal variability of the atmospheric fields, resolving many small-scale sub-synoptic events such as sea breezes and thunderstorms. Numerical experiments indicate that NCEP global forecasts are as good as the reanalysis for the large scale forcing, but that the nearshore atmospheric forecasts were sensitive to persisted versus observed SSTs. ROMS forecasts were improved through the use of the COARE atmospheric boundary layer algorithm, with idealized and realistic numerical experiments demonstrating the sensitivity to using specified wind stress versus specified wind speed with COARE generated stresses due to the feedback from the SST. Heat fluxes were also affected. The high spatial and temporal resolution available from locally generated RAMS forecasts provided forcing that generated better ocean forecasts than operational atmospheric forecasts only available at 12-hour intervals. Initialization using MODAS fields is complicated by the large-scale correlations that smear the local near shore features. Shear mixing in the interior is an important sensitivity that merits additional work. CODAR surface currents remain the dominant assimilation dataset for improving forecast results, with methods of melding 2-D surface currents with subsurface towed/AUV derived currents an important area to be explored.

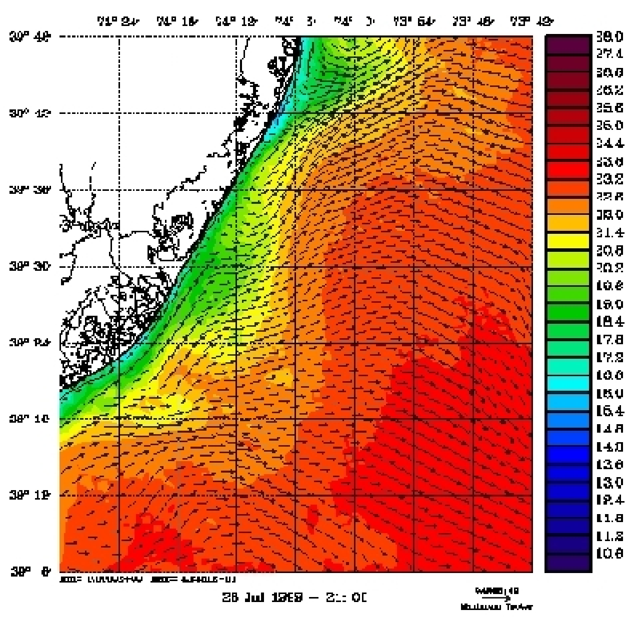

Figure 1: ROMS forecast of surface currents and temperature with RAMS atmospheric forcing and assimilation of CODAR.

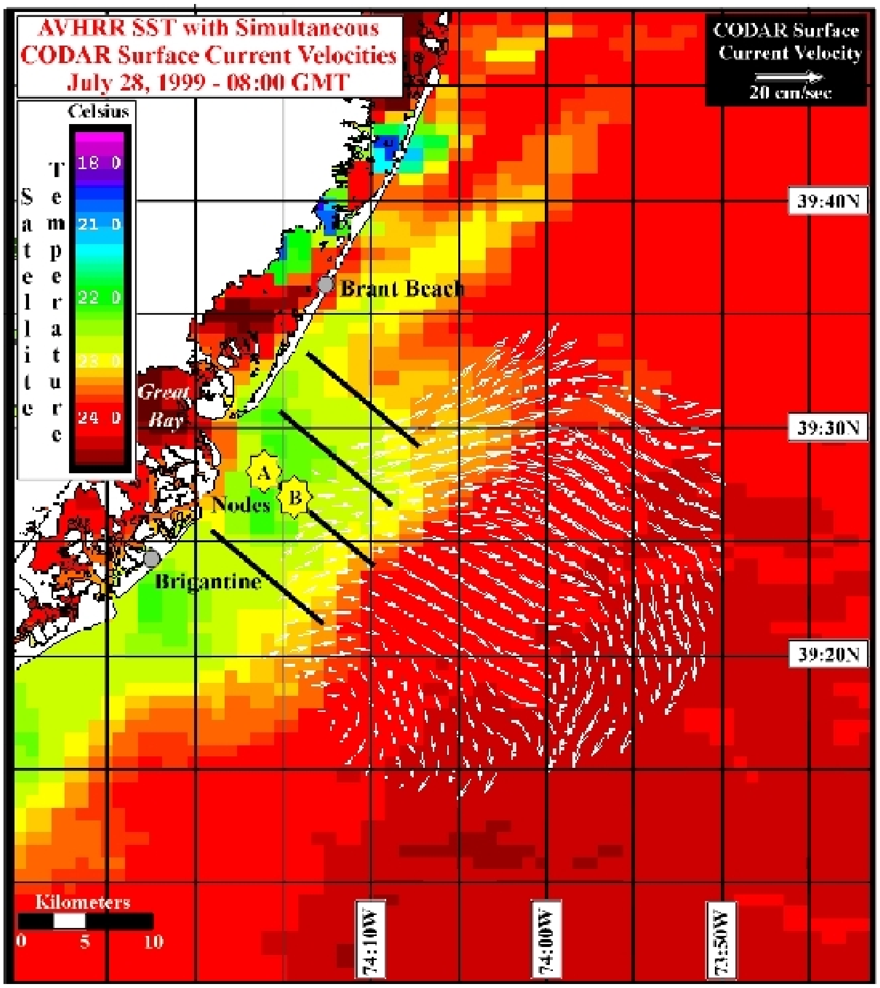

Figure 2: CODAR surface currents and AVHRR surface temperatures with shipboard sampling transects overlaid.

A stormy and dry spring and summer resulted in a much deeper thermocline in the Middle Atlantic Bight then observed since monitoring began in 1993. Upwelling of cold, lower layer water was confined closer to shore than in previous years. Nevertheless, the nearshore subsurface jet that runs alongshore towards the south was still observed in the cold upwelled water. Again, this region was associated with the highest concentrations of phytoplankton. Adaptive sampling surveys focused first on the source region to the north of the jet, followed by the region to the south where it encounters the shallower topography of an ancient river delta. The source region for the jet appears to be offshore about 20-30 km north of the LEO site. The jet increases in intensity as it approaches and passes LEO, then appears to filament as it encounters the numerous kilometer scale sand ridges present on the ancient river delta.

IMPACT/APPLICATIONS

LEO-15 was cited as the coastal observing system with sufficient continuity and level of integration to be considered as an example of a pilot project by the National Ocean Research Leadership Council in their U.S. Plan for an Integrated, Sustained Ocean Observing System.

The first joint Sigma Coordinate Modeling Meeting was held in September 1999, bringing together users of both the POM (Princeton Ocean Model) and ROMS communities, as well as other interested scientists. As a result of this meeting, efforts are underway to move forward on the definition and maintenance of an advanced "community" model of generalized sigma type.

A total of 21 abstracts related to the summer Coastal Predictive skill experiments were submitted to the 2000 AGU/ASLO Ocean Sciences meeting in San Antonio, with several submissions by students.

Web access peaks in the summer with averages over 5,000 accesses and 22,000 hits per day.

TRANSITIONS

The ocean circulation model developed for COMOP is being adapted to the Gulf of Maine by the USGS for ECOHAB applications (Signell, PI). It has also been configured for use on the U.S. West Coast (McWilliams, PI) and in the CalCOFI region (Miller, PI), as well as in the Coastal Gulf of Alaska and Bering Sea (Hermann, PI).

Bottom Boundary Layer algorithms developed for COMOP are actively shared with NRL researchers (Tim Keen) to predict resuspended sediment concentration profiles and the associated inorganic scattering contribution to the total scattering. The new BBLM is also being coupled to existing shelf circulation models for the Gulf of Maine (Wendell Brown).

RODAN is being transitioned for use by all HyCODE researchers to provide widespread access to future datasets.

Towed instrumentation developed for COMOP is being used by several Rutgers and Stevens Institute of Technology researchers for estuarine studies.

COMOP was one of the first examples of an operational Navy center sharing forecast products with researchers in return for validation feedback.

RELATED PROJECTS

Two National Ocean Partnership Program (NOPP) grants were awarded to enhance the summer CPSE in 1998 and 1999. LEO-15 was named one of the ONR HyCODE validation sites. All three of these projects are nearly inseparable from COMOP.

NRL (Jerry Miller) was funded to enhance the in situ observation network and fly the Microwave Salinity Mapper over LEO in 2000. The Johns Hopkins University Applied Physics Lab was funded by NASA to fly an aircraft-mounted GPS altimeter over LEO for the next 3 summers. NRL is using CPSE data to improve the shallow water characteristics of MODAS.

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